**II. Physical and Chemical Monitoring**

**Overview**

The physical and chemical properties of the water at the study site should be measured regularly for possible correlation with any changes observed on the reef. Most coral species can survive only within narrow salinity and temperature ranges, and any marked changes in parameters such as light transmission, sedimentation, and dissolved oxygen may affect the growth or survival of reef organisms.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Why/Where It May Be of Special Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>Recent concern over widespread “bleaching” and its possible association with high water temperatures, along with more general concern over global warming have increased the interest in water temperature data from coral reef environments.</td>
</tr>
<tr>
<td>Dissolved oxygen</td>
<td>Necessary for survival of marine animals; low levels may indicate high bacterial concentrations.</td>
</tr>
<tr>
<td>Salinity</td>
<td>Of interest near reefs which may be subjected to fresh water influx (e.g., those near rivers), or high salinity and warm water from water-making facilities.</td>
</tr>
<tr>
<td>pH</td>
<td>Unlikely to vary much over time, but changes may indicate that the reef is being affected by a new source of pollution, or by additional pollution from an existing source.</td>
</tr>
<tr>
<td>Light transmission</td>
<td>The amount of light available for photosynthesis of free-living and symbiotic algae affects the growth of corals and other organisms.</td>
</tr>
<tr>
<td>Sedimentation</td>
<td>Sediments may reduce light available for photosynthesis, deplete dissolved oxygen, and cause smothering of organisms.</td>
</tr>
<tr>
<td>Nutrients</td>
<td>Increases can lead to changes in the relative abundance of organisms such as macroalgae or bacteria.</td>
</tr>
<tr>
<td>Current speed and direction</td>
<td>Currents transport nutrients, sediments and other pollutants, food, fish and coral larvae to the coral reef ecosystem.</td>
</tr>
</tbody>
</table>

Water temperature, salinity, turbidity, and dissolved oxygen should be measured as part of a minimal monitoring program. In the open ocean, these may fluctuate very little over time, but in shallow, nearshore areas, wider variations can occur. For example, heavy rainfall may cause salinity and temperature to decrease. All of these parameters can be conveniently measured in the field.
For example, an instrument such as the Hydrolab Datasonde will measure temperature, salinity, dissolved oxygen, pH, and conductivity while remaining at the site for continuous monitoring. What you choose to measure and how you measure it will depend on your monitoring objectives and budget.

**TEMPERATURE**

Water temperature can be measured by holding a simple thermometer 0.5 m below the surface and/or at the depth of the study site. Read the water temperature while the thermometer bulb is still in the water. A maximum/minimum thermometer left at the site will record the warmest and coldest that the water has been since the thermometer was last set. Monthly monitoring is generally adequate unless temperature is a special concern because of coral bleaching or effluent from a nearby thermal power plant.

A thermistor is a temperature sensor. A thermistor coupled with a microprocessor and placed inside a waterproof housing can automatically take the water temperature at periodic intervals.

---

**Using a Thermistor/Microprocessor**

- **You** should calibrate a new thermistor using a National Bureau of Standards thermometer, and recalibrate it each time it’s deployed. The instrument should generally be returned to the manufacturer for recalibration every 1% years.

- Attach the instrument to a survey or reference stake on the reef with several plastic cable ties or similar material.

- The instrument may function for 1 to 2 years with the same batteries, but to guard against loss or distortion of data, it’s best to retrieve the unit every six months, download the data, and replace the batteries. If you have a second instrument, you can replace the unit immediately so there are no gaps in the data.

Both the Ryan and the Hugrun Seamon instruments can be read to within 0.1 °C precision, and can be set to record the temperature at designated intervals up to every two hours. The Ryan unit will drift up to 0.3°C over a period of months if not recalibrated. You can retrieve the data and create a thermograph showing the date and time by using two computer programs: Microsoft’s “Windows” and Ryan’s “Windows” software.

The Hugrun Seamon instrument comes with a software program that will create tables and graphics showing the date, time, and temperature. Data may be imported into Lotus or QuattroPro software for more complex graphics and analysis.
**Dissolved Oxygen**

Dissolved oxygen is the amount of oxygen available for respiration by aquatic organisms and is expressed as mg\(O_2\) per liter of water (or parts per million, ppm). Dissolved oxygen can be easily measured in the field using an oxygen meter or inexpensive test kit based on titration.

**Salinity**

Salinity is an estimate of the concentration of dissolved salts in seawater, expressed as S \(\text{o/oo}\) or S ppt (parts per thousand). It can be used to detect an influx of fresh water from either natural or anthropogenic sources. Salinity is typically 34 to 37 ppt in reef waters. At sites where underground fresh water sources exist, it’s best to measure both bottom and surface salinity. Here are three instruments that can be used to measure salinity.

- **Hydrometer:** A hydrometer is a glass tube that measures salinity by comparing the weight of a seawater sample to that of fresh water. The seawater should be collected in a clean bottle at least 0.5 m below the surface. The hydrometer is put in a jar filled with the seawater until the hydrometer floats. Using the number on the hydrometer scale at the water surface and the temperature of the water, you can determine the salinity from tables provided with the hydrometer. Although a hydrometer can be used in the field, it is fragile and easily broken, so the test is best done in the lab.

- **Refractometer:** This instrument is more expensive than a hydrometer, but it’s less fragile, easy to use in the field, and provides sufficiently precise data for most purposes. The refractometer, which resembles a small telescope, measures the bending of light as it passes through seawater as a result of the dissolved salts. You place a few drops of the water sample under the transparent cover and look through the eyepiece to see the reading on a calibrated scale. The refractometer must be frequently recalibrated using distilled water. This instrument may be unreliable in waters that have a high suspended sediment load.

- **Salinity Meter:** A salinity meter often combines temperature and conductivity sensors in a single unit. The salinity meter is comprised of a probe connected by an electric cable to a deck readout. The probe is lowered to the desired depth and salinity read from the meter dial, or the data can be transmitted directly to a computer.
MEASUREMENT OF pH

The pH of a water sample, which is a measurement of the hydrogen ion concentration, ranges from 1 to 14, with “1” being the most acidic and “14” the most alkaline; a pH of “7” is considered “neutral”. The pH of reef waters (ranging from 7.5 to 8.4) does not vary much over time, but may be valuable to record for long-term monitoring as changes in pH may indicate that the reef is being affected by pollution. You can use a simple pH meter, or a more elaborate meter that will also measure temperature, salinity, dissolved oxygen and conductivity.

WATER TRANSPARENCY AND LIGHT

Light is essential for zooxanthellae, the single-celled plants which are found in most stony corals, octocorals and zoanthids, and some anemones and jellyfish. Suspended particles in the water absorb and scatter light, reducing light penetration. You can measure light transmission directly with a transmissometer, or indirectly, by measuring visibility in water with a Secchi disc, or by measuring the amount of scattered light with a turbidimeter. The measurements taken in these different ways do not have any simple mathematical correlations, e.g., the Secchi disc depth cannot be used to predict the turbidimeter reading, and suspended matter concentrations are not directly correlated with the percent of light transmission.
Vertical transparency: To measure the water’s vertical transparency, mark off meters on a line or rope and attach it to a weighted disc, 20 to 30 cm in diameter. The disc can be white or divided into four equal sections in an alternating black and white pattern. The rope needs to be made of a material that does not stretch, e.g., polypropylene or double-braided nylon. Lower the disc into the water until you can no longer see it. Slowly pull up the disc until it just reappears and record the depth at that point. If the bottom is visible, record "B" for bottom. For good comparative data, it is best to take the readings at about the same time of day at different locations, or at the same location over time.

Horizontal transparency: The Secchi disc can also be used to measure horizontal visibility in the water. One person holds the disc perpendicular to and 0.5 m below the water surface with the end of a tape measure; a second person swims away from the disc, drawing out the tape measure until the disk disappears from view, then slowly returns until the disc reappears, and records the distance.
Turbidimeter

A turbidimeter or nephelometer determines water clarity in the laboratory by passing a beam of light through a water sample and measuring the amount of light scattered by the particulates at a 90° angle to the light beam. The amount of scattered light is directly proportional to the turbidity. Use water samples of about 100 ml in volume collected from your study site. The turbidimeter reads in Nephelometer Turbidity Units (NTU’s).

You must be careful in interpreting turbidimeter readings, because they can fluctuate widely due to the small volume of each sample, the drift in the instrument and other factors not directly pertaining to water clarity. Three samples should be analyzed and the average of the three used as the data value. Look for consistent trends in the data, or substantial increases or decreases over time. For example, if after several months of values of less than 1.0 NTU at a particular site you get a series of values over 2.0 NTU, you can generally conclude that turbidity has increased significantly. Smaller changes are harder to interpret.

Measuring Light Penetration

Light transmission: A Martek transmissometer is used to measure the amount of light that is not scattered or absorbed by particulates or soluble molecules in a one-meter path of water. This instrument is expensive, heavy and awkward to carry, but it can provide a field test that is not affected by the angle of the sun or time of day.

Photosynthetically active radiation: PAR is the amount of sunlight available to plants for photosynthesis (wavelengths of 380 to 710 nm). The amount of PAR can vary with cloud cover, phytoplankton in the water column, or turbidity. A Li-Cor quantum meter with an underwater sensor and a cable for lowering the sensor over the side of a boat at the study site can be used to record PAR at selected depths and calculate light attenuation.

Ultraviolet radiation: The decrease in ozone in the upper atmosphere and concurrent increase in UV radiation reaching the earth’s surface has made data on the amount of UV radiation reaching the reef of special interest. There is some evidence that bleaching may be caused by a synergism between higher water temperatures and higher UV intensities. UV radiation (shorter wavelengths than PAR) can be monitored continuously with a spectroradiometer by installing a sensor permanently on the reef.

Suspended Matter

The amount and type of matter suspended in the water column affect light transmission and can be measured to monitor changes in water quality. Measuring the concentration of suspended matter in reef waters requires collection of samples in the field and filtration in the lab. In many locations, the concentrations are so low that it may take several liters of water to get a detectable amount of particulate matter on the filter. However, baseline data on suspended matter concentrations are valuable for comparison purposes.
Measuring Suspended Matter

1) Weigh a 0.45 micron Millepore filter that has been rinsed with distilled water and dried.

2) With a Van Dorn or similar water sampler, collect at least three samples of seawater (1 liter each) at just below the surface and at approximately 1 meter from the bottom. Transfer each sample to a clear polyethylene bottle.

3) In the lab, shake the sample and then filter a measured volume of sample water through the Millepore filter using a vacuum pump. Let it dry (at 60°C if possible) until the weight is constant.

4) To determine the mg/l suspended matter, divide the difference between the final filter weight and the initial weight after filtration by the number of liters in the sample (in this example, 1). Calculate the average value for your samples.

\[
\text{mg/l suspended matter} = \frac{\text{Final weight} - \text{initial weight (mg)}}{\text{No. liters of filtered sample}}
\]

In determining the possible causes of an increase in suspended matter, you need to consider the duration as well as the rate of change. Increases may occur after storms which stir up marine sediments or cause runoff from the land, during plankton blooms, and during dredging operations.

Reference


Sediment Deposition

Data on sedimentation rates are especially important for reefs vulnerable to sedimentation from dredging operations and erosion. By collecting samples both at and above the substrate, you can estimate the sediment being stirred up from and transported along the bottom (the "bedload" component) as well as the sediment that is settling out of the water column.
Measuring Sediment Deposition

1) Using straight-sided plastic jars (about 10-cm high and 8-cm diameter) with tight-fitting lids, secure the open jars to reference stakes at 50 cm and 10 cm above the substrate. Take at least three samples at each height at each location.

2) After a selected number of days (generally no more than 14), cap the jars underwater and bring them to the laboratory. Remove any small organisms in the jar with tweezers.

3) Weigh #2 Whatman filters and filter the samples by pouring the jar contents through the filter, using a Buchner funnel.

4) Rinse each filter several times by running distilled water gently through the filter to remove salts from the sediment.

5) Dry the sediment filters in a drying oven at 70°C until a constant weight is attained.

6) Calculate the sedimentation rate as mg of sediment per cm² per day. The sediment weight is the total weight minus the filter weight, and the area of the jar opening is $\pi r^2$ ($r =$ radius in cm).

$$\text{Sedimentation Rate} = \frac{\text{Sediment Weight}}{\text{No. of days at site} \times \pi r^2}$$
Chlorophyll

Phytoplankton, the microscopic plants that drift in the water column, contain chlorophyll, which captures energy from sunlight for photosynthesis. By measuring the amount of chlorophyll a, b, and c in a water sample, you can estimate the concentrations of phytoplankton. Because a nutrient influx may cause a phytoplankton bloom, an increase in chlorophyll may also indicate an increase in nutrients.

Measuring Chlorophyll

1) Filter a Z-liter water sample (which was kept in the dark and on ice) through a 47-mm glass fiber filter with 0.2 atm vacuum while adding 3-5 drops of MgCO₃. (The volume of water needed will depend on the amount required to produce a visible color on the filter.) Dry the filter under vacuum.

2) Place the filter in a 15-ml centrifuge tube, add 10 ml of 90% acetone, and shake thoroughly.

3) Cover the tube with aluminum foil and put in refrigerator to extract for 18-24 hours, then mix and centrifuge the contents for 10 minutes at 4,000 rpm.

4) Carefully pour off the liquid portion into a 10-cm path length spectrophotometer cuvette.

5) While the sample is at room temperature, use a spectrophotometer to quickly measure the extinction at 750, 664, 647, and 630 nm. Correct the measured extinction by subtracting the 750-nm reading from the 664, 647, and 630-nm readings. (At 750 nm, no pigment absorbance shows.)

6) Calculate the amount of chlorophyll in the sample using these formulas:

   Chlorophyll a = 11.85 E₆₆₄ - 1.54 E₆₄₇ - 0.08 E₆₃₀
   Chlorophyll b = 21.03 E₆₄₇ - 5.43 E₆₆₄ - 2.66 E₆₃₀
   Chlorophyll c = 24.52 E₆₃₀ - 1.67 E₆₆₄ - 7.60 E₆₄₇

   E = Absorbance at noted wavelengths (corrected by 750-nm reading)

   \[
   \mu g/l = \frac{\text{Chlorophyll a, b, c} \times \text{ml acetone}}{\text{No. of liters filtered seawater} \times \text{cm path length}}
   \]

Reference

Although it is expensive, a fluorometer also provides a sensitive measurement of chlorophyll a from a smaller sample of filtered water than does the spectrophotometer. You can place a test tube of the water sample in the fluorometer, or use a pump and tubing to do continuous flow measurements at the site. To determine the concentration of chlorophyll a in the sample, use the following formula:

$$\text{Chlorophyll a, } \mu g/l = F_x (r/r-1) (R_b - R_d)$$

where $F_x = \text{response factor for the sensitivity setting used; } R_b = \text{fluorescence of sample extract before acidification; } R_d = \text{fluorescence of sample extract after acidification; and } r = \text{the before-to-after acidification ratio of a pure chlorophyll a solution.}$

**Reference**


**Bacterial Concentrations**

Checking for bacteriological pollutants is important if you suspect contamination from boat effluent, sewage pipes, old septic tanks, overloaded leach fields, or runoff from agriculture. Marine waters are usually examined for coliform bacteria by counting bacteria cultured on petri dishes. To prepare a bacterial culture requires an autoclave, incubator $\text{H}_2\text{O}$ bath, refrigerator, $\text{pH}$ meter, and depth sampler. If you have an incubator, you can obtain a kit from the Hach Company that contains materials for culturing 80 to 100 samples. If you do not have the expertise to analyze the samples yourself, you can send them out to a laboratory. Breweries and sugar processing plants usually have bacterial labs.

**Reference**

**Nutrients**

Nutrients are naturally found in coastal waters and required by organisms on the reef. Coral reefs typically occur in warm waters with very low nutrient concentrations. High concentrations of nutrients can cause phytoplankton or algal blooms. As these algae decompose, dissolved oxygen concentrations may be greatly reduced, especially in shallow, near shore waters, posing a potentially lethal threat to the other reef organisms. High nutrient concentrations may also indicate contamination from bacteria species such as *E. coli*, that can be dangerous to human health. The presence of these blooms or bacteria may indicate pollution from sewage, industrial runoff and agriculture.

**Nutrient Sampling**

Ideally, both the water column and bottom sediments are sampled at least four times a year to monitor the nutrients in a reef system. This requires collection of:

- water samples for analysis of dissolved inorganic and organic nutrients (nitrates, nitrites, ammonia, phosphates, and silicates); and

- sediment core samples for total carbon, nitrogen, phosphorus (C, N, P).

Sediments store nutrients and may provide an integrated record of nutrient conditions. The history of nutrient loading from upwelling (the process by which deeper water is brought to the surface by currents and winds) can be determined by trace metal (Cd, Mn, Ba) analyses in coral cores. Humic and fulvic acids correlate with nutrients carried from land in fresh water runoff. (See “Core samples,” III-l 1.)

**Nutrient Analysis**

While basic data on nutrient composition are useful, nutrient analysis is not simple and good data are difficult to obtain. Most researchers lack the laboratory facilities needed for nutrient analyses, but you can arrange to ship samples to a laboratory for analysis. These samples may require special treatment such as instant cooling or the addition of fixatives before shipping in order to halt any biological activity that may alter nutrient concentrations. Ask for specific shipping instructions and guidance from the testing laboratory.

Because phytoplankton rapidly remove nutrients from the water, nutrient analysis may not show a nutrient influx where a phytoplankton bloom is present. Where there is concern about the possible presence of nutrients, it may be appropriate to supplement nutrient analysis with chlorophyll measurement and bacterial sampling, discussed earlier.

In the fall after the rainy season, the nutrient-rich waters of the Orinoco, the second largest river in South America, are discharged into the Gulf of Paria, which separates Trinidad from Venezuela, creating a plume of fresh water that is swept northwest into the Caribbean by ocean currents. Analysis of water samples can indicate the extent of the plume.
The Orinoco Plume

The fresh water of the Orinoco plume nourishes marine algae, causing a phytoplankton bloom that can be detected by Landsat satellites. The geographical extent of the plume and the relative mixing of fresh water with seawater can be determined by using images from Coastal Zone Color Scanners mounted on satellites to estimate the average pigment concentration from phytoplankton near the surface -- the ratio of the blue (443 nm) or blue-green (520 nm) wavelengths to the green (550 nm).

By the time the Orinoco plume is southwest of Puerto Rico, the fresh water has mixed with sea water, the nutrients have been taken up by the phytoplankton and recycled many times, and the silicates have usually been tightly recycled by the diatoms, so that the water is only slightly different chemically from "normal" Caribbean sea water. However, the salinity may still be slightly lower than average, the concentration of silicates slightly higher, and the water may look reddish-brown and turbid. Chlorophyll breakdown products from the algal bloom can be detected using a spectrophotometer.

When the plume reaches the Mona Passage, west of Puerto Rico, it is usually imperceptible. However, sometimes a prolonged south wind (over several days) will push the plume north instead of northwest, causing the seawater to turn brownish overnight with a dramatic decrease in water clarity from Antigua to St. Martin, and up as far as the Virgin Islands. The presence of the plume can be detected by checking for decreased salinity and an increased concentration of silicates (3 to 5 μM).

Reference

CURRENTS

It’s important to know the direction and velocity of the prevailing currents in the area of your study site because they transport larval reef organisms as well as harmful sediments and pollutants such as oil.

Current meters that can be left *in situ* at a study site are very expensive. To get an approximate idea of their passage through the water, or release drift devices ("drogues") and take sightings on their successive positions. Drogues are probably the best indicators of currents in small, semi-contained water masses with sluggish or slow currents.

![Example of Currents](image)
A variety of types of drogues can be purchased or constructed. The drogue apparatus should include a buoy that is large enough to support a flagpole, radar reflector mast or radio antenna, and to prevent the weight of the drogue from pulling it underwater. To ensure that the drogue is influenced by water currents rather than wind, the surface area of the parts in the water must be greater than the surface area of parts exposed to the air. The larger the drogue, the more precise the measurements can be, so use as large a drogue as practical.